Certification of Translation

(Japanese Patent Application No. 2000-190,826)

I, the undersigned, Sawako KODAMA residing at 1-25-5-204, Yutenji, Meguro-ku, Tokyo 153-0052, JAPAN do solemnly and sincerely declare that I am well acquainted with the Japanese language and the English language and that the attached English translation of the Japanese Patent Application No. 2000-190,826 filed June 26, 2000 is an accurate translation to the best of my knowledge and belief from the Japanese language into the English language.

Date: March 9, 2006

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[DOCUMENT NAME] SPECIFICATION

[TITLE OF THE INVENTION]

LIGHT SOURCE UNIT, EXPOSURE APPARATUS, MAKING METHOD OF EXPOSURE APPARATUS, AND DEVICE MANUFACTURING METHOD

[CLAIMS]

[CLAIM 1] A light source unit, said unit comprising:

a light amplifying unit which includes an optical waveguiding member mainly made of any one of phosphate glass and bismuth oxide glass doped with a rare-earth element, and amplifies incident light; and

a wavelength conversion unit which converts a wavelength of light emitted from said light amplifying unit.

[CLAIM 2] The light source unit according to Claim 1, wherein said optical waveguiding member is an optical fiber which has a core to waveguide light, and a cladding arranged in the periphery of said core.

[CLAIM 3] The light source unit according to Claim 2, wherein said optical fiber is arranged linearly.

[CLAIM 4] The light source unit according to one of Claims 2 and 3, wherein said light amplifying unit further includes at least a container to house said optical fiber.

[CLAIM 5] The light source unit according to any one of Claims 1 to 4, wherein said wavelength conversion unit includes at least one nonlinear optical crystal to perform wavelength conversion.

[CLAIM 6] An exposure apparatus that forms a predetermined pattern on a substrate by irradiating an exposure light on said substrate, said exposure apparatus comprising:

the light source unit according to any one of Claims 1 to 5 as a light source unit which generates light which wavelength belongs to a predetermined bandwidth including a wavelength of said exposure light.

[CLAIM 7] The exposure apparatus according to Claim 6, wherein

said light source unit generates said exposure light having a wavelength of 200nm and under.

[CLAIM 8] A making method of an exposure apparatus that forms a predetermined pattern on a substrate by irradiating an exposure light on said substrate via an optical system, wherein adjustment of properties in said optical system is performed by using light which wavelength belongs to a predetermined bandwidth including a wavelength of said exposure light, said light generated by the light source unit according to any one of Claims 1 to 5.

[CLAIM 9] A device manufacturing method including a lithographic process, wherein exposure is performed using said exposure apparatus according to one of Claims 6 and 7 in said lithographic process.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[RELEVANT TECHNICAL FIELD TO THE INVENTION]

The present invention relates to a light source unit, an exposure apparatus, a method of making the exposure apparatus, and device manufacturing method. More particularly, the present invention relates to a light source unit which emits light with a desired wavelength, an exposure apparatus which comprises the light source unit, a method of making the exposure apparatus which uses the light which the light source unit according to the present invention generates, and a device manufacturing method using the exposure apparatus according to the present invention.

[0002]

[RELATED ART]

Conventionally, in the lithographic process to manufacture a semiconductor device (integrated circuit), a liquid crystal display device, and the like, various exposure apparatus were used. In recent years, as these types of exposure apparatus, the reduction projection exposure apparatus such as the so-called stepper or the so-called scanning stepper is mainstream, from the viewpoint of having high throughput. With the reduction projection exposure apparatus, a fine circuit pattern formed on a photomask or a reticle is reduced, projected, and transferred onto a substrate such as a wafer or a glass plate, which surface is coated with a photoresist via a projection optical system.

[0003]

However, the exposure apparatus such as the projection exposure apparatus require high resolution, along with high throughput. Using the wavelength of the illumination light for exposure λ and the numerical aperture of the projection optical system N.A., the resolution R, and the depth of focus DOF of the projection exposure apparatus are respectively expressed in:

$$R = K\cdot\lambda / N.A. \quad \cdots\cdots(1) \text{ and}$$

$$DOF = \lambda /2\ (N.A.)^2 \quad \cdots\cdots(2).$$

[0004]

As is obvious from equation (1), three ways can be considered to obtain a smaller resolution R, that is, to decrease the minimum pattern line width that can be resolved; (a) reduce the proportional constant K, (b) increase the N.A., (c) reduce the wavelength of the illumination light for exposure λ. The proportional constant K, in this case, is a constant that is determined by the projection optical system or the process, and is normally a value around 0.5 to 0.8. The method of decreasing the constant K is called super-resolution in a broad sense. Up until now, issues such as improvement of the projection optical system, modified illumination, phase shift reticle have been studied and proposed, however, there were drawbacks such as the patterns suitable for application being restricted.

[0005]

On the other hand, as can be seen from equation (1), the resolution R can be reduced by increasing the numerical aperture N.A., however, at the same time, this means that the depth of focus DOF is small, as is obvious from equation (2). Therefore, increasing the N.A. value has its limits, and normally, the appropriate value is around 0.5.

[0006]

Accordingly, the most simple and effective way of reducing the resolution R is to reduce the wavelength of the illumination light for exposure λ.

[0007]

For such reasons, conventionally, the g-line stepper and the i-line stepper that use an ultra-high pressure mercury lamp as the light source for exposure to emit the emission line (such as the g line or the i line) in the ultraviolet light region were mainly used, as the stepper or the like. However, in recent years, the KrF excimer laser stepper that uses a KrF excimer laser as the light source to emit a KrF excimer laser beam having a shorter wavelength (wavelength: 248nm) is becoming mainstream. And currently, the exposure apparatus that uses the ArF excimer laser (wavelength: 193nm) as the light source having a shorter wavelength is under development. The excimer laser, however, has disadvantages as the light source for the exposure apparatus, such as, the size

being large, and the maintenance of the laser being complicated and expensive because of using poisonous fluorine gas.

[0008]

Therefore, the method of utilizing the nonlinear optics effect of the nonlinear optical crystal to convert light with a long wavelength (infrared light and visible light) to an ultraviolet light with a shorter wavelength and using the ultraviolet light as the exposure light, is gathering attention.

[0009]

[PROBLEMS TO BE SOLVED BY THE INVENTION]

With the method of using the nonlinear optical crystal as described above, since it is hard to say that the generation efficiency of the nonlinear optics effect of the currently utilizable nonlinear optical crystal is high, a light having high intensity needs to be irradiated to the nonlinear optical crystal in order to obtain a wavelength converted light having sufficient intensity. Therefore, it may be considered that a laser beam emitted from a laser oscillation source such as a semiconductor laser output is amplified by a fiber amplifier which includes an optical fiber doped with a rare-earth element such as an erbium (Er) as an amplifying fiber, and is irradiated to the nonlinear optical crystal. With the current fiber amplifier, however, a long amplifying fiber has been required to

obtain sufficient amplification, and the size reduction has been difficult. In addition, because a long amplifying fiber has been used, broadening in spectral width due to guided Raman scattering or self-phase modulation has increased.

[0010]

In addition, to efficiently generate a second harmonic wave and the like by the nonlinear optics effect using the nonlinear optical crystal, a linearly polarized beam of a specific direction which corresponds to the crystal direction of the nonlinear optical crystal needs to be incident on the nonlinear optical crystal. However, on arrangement of a long amplifying fiber, the amplifying fiber is circularly winded, and in this case a polarized state when being incident on the amplifying fiber is not always maintained at an output end, due to effect such as asymmetric stress in a diameter direction generated in the amplifying fiber. Therefore, in order to optimize the wavelength conversion efficiency, a mechanism such as polarization control needs to be added.

[0011]

The present invention has been made in consideration of the situation described above, and has as its first object to provide a light source unit with a simple arrangement that can efficiently generate a light having a predetermined wavelength.

[0012]

It is the second object of the present invention to provide an exposure apparatus that can efficiently form a predetermined pattern on a substrate with good precision and a method of making the exposure apparatus.

[0013]

And, it is the third object of the present invention to provide a device manufacturing method that can efficiently manufacture the device with high integration and high performances.

[0014]

[MEANS FOR SOLVING THE PROBLEMS]

The light source unit according to the present invention is a light source unit comprising: a light amplifying unit (167) which includes an optical waveguiding member (175) mainly made of any one of phosphate glass and bismuth oxide glass doped with a rare-earth element, and amplifies incident light; and a wavelength conversion unit (163) which converts a wavelength of light emitted from the light amplifying unit.

[0015]

With the light source unit, instead of the optical waveguiding member such as the conventional amplifying fibers mainly made of silica glass and doped with a rare-earth element, the optical waveguiding member mainly made of either phosphate glass or bismuth oxide glass densely doped with a rare-earth element is used. So, the optical

waveguiding member, being short in length, can amplify the incident light with high amplification. Therefore, light with high luminance can be supplied to the wavelength conversion unit, while reducing change in the polarized state that is generated when the light passes through the optical waveguiding member. In addition, upon amplification, the length of the path where the light passes through is shorter, therefore, broadening in spectral width due to guided Raman scattering or self-phase modulation can be suppressed. Accordingly, a narrow-banded wavelength converted light can be efficiently generated with a simple arrangement.

[0016]

With the light source unit according to the present invention, the optical waveguiding member can have the arrangement of an optical fiber (175) which has a core to waveguide light, and a cladding arranged in the periphery of the core. This fiber may also be a dual cladding fiber that has a dual cladding structure. In such a case, connection and the like to the propagation fiber used for light guiding is simplified, thus, the light source unit can be realized more easily.

[0017]

The optical fiber can be arranged linearly. In such a case, since the asymmetric stress generated in the diameter direction, which is the cause of change in the polarized state, can be prevented, it becomes possible to

obtain output light that maintains the polarized state when the light is incident.

[0018]

In addition, the light amplifying unit can have the structure of further including at least a container (176) to house the optical fiber. In such a case, the change in the surrounding environment of the amplifying fibers that is the cause of change in the polarized state can be prevented; therefore, a stable wavelength conversion can be performed.

[0019]

With the light source according to the present invention, the wavelength conversion unit may have the structure of including at least one nonlinear optical crystal (183, 186, 187, 193, 196) to perform wavelength conversion on the incident light. In such a case, by irradiating light with high luminance emitted from the light amplifying unit, a high-powered wavelength converted light can be obtained.

[0020]

The exposure apparatus according to the present invention is an exposure apparatus that forms a predetermined pattern on a substrate by irradiating an exposure light on the substrate, the exposure apparatus comprising: the light source unit (16) according the present invention as a light source unit which generates light which wavelength belongs to a predetermined

bandwidth including a wavelength of the exposure light.

[0021]

With the exposure apparatus according to the present invention, the light source unit can have a structure of generating the exposure light, which has a wavelength of 200nm and under. In such a case, by generating an exposure light which wavelength spectral is narrow in the light source unit according to the present invention, exposure with favorable precision can be efficiently performed on the substrate, and a fine pattern corresponding to the short wavelength of 200nm and under can be precisely formed on the substrate.

[0022]

When the exposure apparatus according to the present invention has a mask on which a predetermined pattern is formed and exposes the substrate via the optical system, on detecting the position of the mask using the light having the wavelength almost the same as the exposure light, by using the light source unit according to the present invention, it becomes possible to efficiently supply the light for positional detection.

[0023]

The method of making an exposure apparatus according to the present invention is a method of making an exposure apparatus that forms a predetermined pattern on a substrate by irradiating an exposure light on the substrate via an optical system, wherein adjustment of

properties in the optical system is performed by using light which wavelength belongs to a predetermined bandwidth including a wavelength of the exposure light, the light generated by the light source unit according to the present invention. With this making method, the adjustment of the optical properties related to the exposure light upon exposure can be performed easily, with high precision.

[0024]

The device manufacturing method according to the present invention is a device manufacturing method including a lithographic process, wherein in the lithographic process exposure is performed using the exposure apparatus according to the present invention. With the device manufacturing method, a device with high integration and high performances can be efficiently manufactured.

[0025]

[EMBODIMENT OF THE INVENTION]

Fig. 1 shows the schematic view of the exposure apparatus 10 related to the embodiment, which structure includes the light source unit related to the present invention. The exposure apparatus 10 is a scanning type exposure apparatus based on the step-and-scan method.

[0026]

The exposure apparatus 10 comprises: an illumination system consisting of a light source unit 16 and an

illumination optical system 12; a reticle stage RST that holds a reticle R serving as a mask which is illuminated by the illumination light for exposure (hereinafter referred to as "exposure light") IL from the illumination system; a projection optical system PL which projects the exposure light IL outgoing from the reticle R onto a wafer W serving as a substrate; an XY stage 14 on which a Z tilt stage 58 holding the wafer W serving as a substrate is mounted; control systems for these parts; and the like.

[0027]

The light source unit 16 is, for example, a harmonic generation unit that emits an ultraviolet pulse light having a wavelength of 193nm (almost the same wavelength as of the ArF excimer laser beam) or an ultraviolet pulse light having a wavelength of 157nm (almost the same wavelength as of the F_2 laser beam). The light source unit 16 is housed within an environmental chamber (hereinafter referred to as "chamber") 11 where the temperature, pressure, humidity, and the like are adjusted with high precision. In the environmental chamber 11, the illumination optical system 12, the reticle stage RST, the projection optical system PL, the Z tilt stage 58, the XY stage 14, and a main body of the exposure apparatus consisting of a main column (not shown in Figs.) on which these parts are arranged, are also housed.

[0028]

Fig. 2 is a block diagram showing the internal structure of the light source unit 16 along with the main controller 50, which performs overall control over the entire exposure apparatus. As is shown in Fig. 2, the light source unit 16 has a structure including a light source portion 16A, a laser controller 16B, a light amount controller 16C, and the like.

[0029]

The light source portion 16A has a structure including a pulse light generation portion 160, a light amplifying portion 161, a wavelength conversion unit 163, a beam monitor mechanism 164, an absorption cell 165, and the like.

[0030]

The pulse light generation portion 160 has a laser light source 160A, photocoupler BS1 and BS2, optical isolator 160B, an electro-optic modulator (hereinafter referred to as "EOM") 160C serving as an optical modulator, and the like. And, each element arranged in between the laser light source 160A and the wavelength conversion unit 163 is optically connected to one another by optical fiber or the like.

[0031]

As the laser light source 160A, in this case, a single wavelength oscillation laser is used, for example, an InGaAsP DFB semiconductor laser, which has an

oscillation wavelength of 1.544μm, continuous-wave output (hereinafter referred to as "CW output") of 20mW, is used. Hereinafter in this description, the laser light source 160A will be referred to as "DFB semiconductor laser 160A", as appropriate.

[0032]

The DFB semiconductor laser is usually arranged on a heatsink, and these are housed in a casing. With the embodiment, a temperature adjustment unit (for example, a Peltier element) is arranged on the heatsink of the DFB semiconductor laser 160A, and the embodiment has a structure so that the laser controller 16B is capable of controlling (adjusting) the oscillation wavelength by controlling the temperature of the temperature adjustment unit.

[0033]

The photocoupler BS1 and BS2 have a transmittance of around 97%. Therefore, the laser beam from the DFB semiconductor laser 160A is branched into two by the photocoupler BS1, and around 97% of the branched beam proceeds toward the photocoupler BS2 at the next stage, whereas, the remaining 3% is incident on the beam monitor mechanism 164. Furthermore, the laser beam incident on the photocoupler BS2 is branched, and around 97% of the branched beam proceeds to the optical isolator 160B, whereas, the remaining 3% is incident on the absorption cell 165.

[0034]

The beam monitor mechanism 164, the absorption cell 165, and the like will be described in detail later on in the description.

[0035]

The optical isolator 160B allows only light proceeding from the photocoupler BS2 to the EOM160C to pass, and prevents light proceeding in the opposite direction from passing. The optical isolator 160B prevents the oscillation mode of the DFB semiconductor laser from changing or noise from being generated, which are caused by the reflecting light (returning light).

[0036]

The EOM160C is a device, which converts the laser beam (CW beam (continuous-wave beam) that has passed through the optical isolator 160B into a pulse light. As the EOM160C, an electrooptical modulator (for example, a double-electrode modulator) that has an electrode structure having performed chirp correction is used, so that the wavelength broadening of the semiconductor laser output by chirp due to temporal change in the refractive index is decreased. The EOM160C emits a pulse light modulated in synchronous with the voltage pulse impressed from the light amount controller 16C. For example, the EOM160C modulates the laser beam oscillated from the DFB semiconductor laser 160A into a pulse light with a pulse width of 1ns and a repetition frequency of 100kHz (pulse

period around 10μs). With regard to the repetition frequency, a value with which the noise effect of the ASE (Amplified Spontaneous Emission) with the fiber amplifier can be prevented is selected.

[0037]

It is preferable to make the emitted light pulsed by using both the impressed voltage to the EOM160C and the supply current control to the DFB semiconductor laser 160A. In such a case, the extinction ratio can be improved. In this manner, it becomes possible to easily generate a pulse light that has a narrow pulse width while improving the extinction ratio, compared with the case when using only the EOM160C, and can also further simplify the control of the oscillation interval and the beginning/end of the oscillation of the pulse light. In addition, it is also possible to use an acousto-optic modulator (AOM) instead of the EOM160C.

[0038]

The light amplifying portion 161 amplifies the pulse light from the EOM160C, and as shown in Fig. 3, is structured including an optical branching device 166 that periodically divides and branches (for example, 128 branches) the pulse light from the EOM160C in temporal order, and the fiber amplifier 167 serving as a plurality of optical amplifiers.

[0039]

As shown in Fig. 3, the fiber amplifier 167 comprises: an

amplifying fiber 175 arranged linearly which serves as an optical waveguiding member; a pumping semiconductor laser 178 generating the pumped light; and a wavelength division multiplexer (WDM) 179 which synthesizes the light emitted from the EOM160C and the pumped light, and supplies the synthetic light to the amplifying fiber 175. And the amplifying fiber 168 and the WDM179 are housed in a container 176.

[0040]

The amplifying fiber 175 is mainly made of phosphate glass, and has a core and a cladding. An optical fiber is used for the amplifying fiber 175, which uses dopants Er, or Er and Yb with high density as the core. With such a phosphate glass optical fiber, rare earth elements such as Er can be doped with a higher density than that of the conventional silica glass optical fiber, and the fiber length required to obtain the same amplification is around 1/100 compared with the conventional silica glass optical fiber. For example, the required fiber length was conventionally around several m to several tens of m, whereas, now only several cm to several tens of cm is needed. Therefore, it becomes possible to arrange the amplifying fiber 175 in a linear state, and in the present embodiment, the amplifying fiber 175 is arranged in a linear state by arranging the amplifying fiber 175 in a linear V groove formed on the surface (plane) of the base member (not shown in Figs.). For the amplifying

fiber 175, it is possible to employ a dual cladding fiber that has a dual cladding structure.

[0041]

With the fiber amplifier 167 having the structure described above, when the pulse light is incident on the amplifying fiber 175 via the WDM179 in a state where the pumped light generated by the pumping semiconductor laser 178 is supplied to the amplifying fiber 175 via the WDM179, and proceeds through the core of the amplifying fiber 175, stimulated emission is generated and the pulse light is amplified. On such amplifying, since the amplifying fiber 175 is much shorter than the conventional fiber, and has high amplification, a pulse light with high luminance is emitted while maintaining the polarized state when the pulse light was incident on the amplifying fiber 175. In addition, since the length of the amplifying fiber 175 is extremely short, the spectral broadening due to guided Raman scattering or self-phase modulation is small.

[0042]

That is, in the case of doping Er, which has the density 100 times compared with the conventional silica glass, to a phosphate glass, the Raman gain coefficient, which is a factor of deciding the threshold value of the Raman scattering, is around twice as much compared with the conventional silica glass. However, even with consideration of this point, the Er doped phosphate glass

can emit light having the intensity of around 50 times more than in the case of conventional silica glass. In addition, since the amplification per unit length can be increased by around 100 times, the fiber length required to obtain the same amplification can be reduced to around 1/100. Furthermore, since trial calculation can be made that the threshold value of the guided Raman scattering is inversely proportional to the fiber length, by reducing the fiber length to 1/100, light having an intensity of around 100 times can be emitted without being affected by the Raman scattering.

[0043]

In addition, the spectral broadening due to self-phase modulation is almost proportional to the length of the amplifying fiber 175, however, since the length of the amplifying fiber 175 is extremely short compared with the conventional fiber, the spectral broadening due to self-phase modulation can be sufficiently suppressed so that it is much smaller than before.

[0044]

Accordingly, the fiber amplifier 167 in the embodiment can obtain an amplified light having a higher intensity than before, and an amplified light which spectral broadening is narrow. Therefore, a narrow-banded light can be effectively obtained..

[0045]

In addition, since the amplifying fiber 175 is

arranged linearly, and is also housed in the container 176 that has a structure nearly sealed so as to maintain a fixed surrounding environment of the amplifying fiber 175, the emitted light from the amplifying fiber 175 can almost maintain the polarized state at the incident stage.

[0046]

The pumping semiconductor laser 178 generates light having a wavelength shorter (for example, 980nm) than the oscillation wavelength of the DFB semiconductor laser 160A as the pumped light. The pumped light is supplied to the amplifying fiber 175 via the WDM 179, and with this operation, the Er is pumped and the so-called population inversion of the energy level is generated. As will be described later on, the pumping semiconductor laser 178 is controlled by the light amount controller 16C.

[0047]

Also, in the embodiment, in order to suppress the gain difference in each fiber amplifier 167, a part of the output is branched in the fiber amplifier 167, and the output is photo-electrically converted by the photoconversion element 171 arranged on the end of the branch, respectively. The output signals of these photoconversion elements 171 are sent to the light amount controller 16C.

[0048]

The light amount controller 16C feedback controls the drive current of each pumping laser semiconductor 178, so

as to make the light emitted from each fiber amplifier 167 constant (in other words, balanced).

[0049]

Furthermore, with the embodiment, as is shown in Fig. 3, the laser beam split by the beam splitter halfway through the wavelength conversion unit 163 is photo-electrically converted by the photoconversion element 172, and the output signal of the photoconversion element 172 is sent to the light amount controller 16C. The light amount controller 16C then monitors the light intensity of the wavelength conversion unit 163 based on the output signals of the photoconversion element 172, and feedback controls the drive current of the pumping semiconductor laser 178 so that the light output from the wavelength conversion unit 163 becomes a predetermined light output.

[0050]

By having this arrangement, since the amplification of each fiber amplifier 167 is constant, a unified light intensity can be obtained as a whole without an overload on either fiber amplifier 167. In addition, by monitoring the light intensity of the wavelength conversion unit 163, the expected predetermined light intensity can be fed back, and the desired ultraviolet light output can be stably obtained.

[0051]

The wavelength conversion unit 163 includes a plurality of nonlinear optical crystals, and converts the

wavelength of the amplified pulse light (light having the wavelength of 1.544μm) into an eighth-harmonic wave so that ultraviolet light that has the same output wavelength as the ArF excimer laser (wavelength: 193nm) is generated.

[0052]

Fig. 4 shows an example of the arrangement of the wavelength conversion unit 163. Following is a description of concrete examples on the wavelength conversion unit 163, with reference to this Figure. Fig. 4 shows an example of the arrangement when ultraviolet light having the same wavelength as the ArF excimer laser (193nm) is generated by converting the fundamental wave of the wavelength 1.544μm output from the light amplifying portion 161 using the nonlinear optical crystals into an eighth-harmonic wave.

[0053]

At the wavelength conversion unit 163 in Fig. 4, the wavelength conversion is performed in the order of: fundamental wave (wavelength: 1.544μm) → second-harmonic wave (wavelength: 772nm) → third-harmonic wave (wavelength: 515nm) → fourth-harmonic wave (wavelength: 386nm) → seventh-harmonic wave (wavelength: 221nm) → eighth-harmonic wave (wavelength: 193nm).

[0054]

More particularly, the fundamental wave output from the light amplifying portion 161 that has the wavelength

of 1.544μm (frequency ω) is incident on the first stage nonlinear optical crystal 183. When the fundamental wave passes through the nonlinear optical crystal 183, by the second-harmonic generation a second-harmonic wave which frequency is doubled from the frequency ω of the fundamental wave, that is, a second-harmonic wave with a frequency of 2ω (the wavelength is half, which is 772nm) is generated.

[0055]

As the first stage nonlinear optical crystal 183, an LiB_3O_5(LBO) crystal is used, and NCPM (Non-Critical Phase Matching), which is a method of adjusting the temperature of the LBO crystal for phase matching to convert the wavelength of the fundamental wave to a second-harmonic wave, is employed. NCPM is capable of converting the fundamental wave into a second-harmonic wave with high efficiency, since walk-off between the fundamental wave and the second-harmonic wave does not occur within the nonlinear optical crystal, and also because of the advantage that the beam shape of the second-harmonic wave generated does not change by the walk-off.

[0056]

The fundamental wave that has passed through the nonlinear optical crystal 183 without the wavelength converted and the second-harmonic wave generated by the wavelength conversion are respectively provided a delay of a half wave and a single wave at a wavelength plate

184 at the next stage. Only the fundamental wave rotates the polarized direction by 90 degrees, then the fundamental wave and the second-harmonic wave are incident on the second stage nonlinear optical crystal 186. As the second nonlinear optical crystal 186, an LBO crystal is used, and the LBO crystal is used in NCPM at a temperature different from the first nonlinear optical crystal (LBO crystal) 183. In the nonlinear optical crystal 186, a third-harmonic wave (wavelength: 515nm) is generated by sum frequency generation of the second-harmonic wave generated in the first nonlinear optical crystal 183 and of the fundamental wave that has passed through the nonlinear optical crystal 183 without the wavelength converted.

[0057]

Then, the third-harmonic wave obtained in the nonlinear optical crystal 186 and the fundamental wave and the second-harmonic wave that have passed through the nonlinear optical crystal 186 without being converted are separated at the dichroic mirror 187, and the third-harmonic wave reflected on the dichroic mirror 187 passes through the condenser lens 190 and the dichroic mirror 193 and is incident on the fourth stage nonlinear optical crystal 195. Meanwhile, the fundamental wave and the second-harmonic wave that have passed through the dichroic mirror 187 passes through a condenser lens 188 and are incident on the third stage nonlinear optical

crystal 189.

[0058]

The LBO crystal is used as the third stage nonlinear optical crystal 189, and the fundamental wave passes through the LBO crystal without being converted, whereas, the second-harmonic wave is converted to a fourth-harmonic wave (wavelength: 386nm) by second-harmonic generation. The fourth-harmonic wave obtained in the third nonlinear optical crystal 189 and the fundamental wave that has passed through the third nonlinear optical crystal 189 are separated at the dichroic mirror 191, and the fundamental wave that has passed through the dichroic mirror 191 passes through the condenser lens 194 and is reflected on the dichroic mirror 196, and is incident on the fifth stage nonlinear optical crystal 198. On the other hand, the fourth-harmonic wave reflected on the dichroic mirror 191 passes through the condenser lens 192 and reaches the dichroic mirror 193, and is coaxially synthesized with the third-harmonic wave reflected on the dichroic mirror 187 and then is incident on the fourth stage nonlinear optical crystal 195.

[0059]

As the fourth stage nonlinear optical crystal 195, a β-BaB_2O_4 (BBO) crystal is used, and a seventh-harmonic wave (wavelength: 221nm) is generated by sum frequency generation of the third -harmonic wave and the fourth-harmonic wave. The seventh-harmonic wave generated in the

fourth nonlinear optical crystal 195 passes through the condenser lens 197, and is coaxially synthesized with fundamental wave that has passed through the dichroic mirror 191 at the dichroic mirror 196, and is then incident on the fifth stage nonlinear optical crystal 198.

[0060]

As the fifth stage nonlinear optical crystal 198, the LBO crystal is used, and an eighth-harmonic wave (wavelength: 193nm) is generated by sum frequency generation of the fundamental wave and the seventh-harmonic wave. In the arrangement above, instead of the BBO crystal 195 used to generate the seventh-harmonic wave and the LBO crystal 198 used to generate the eight-harmonic wave, it is also possible to use a $CsLiB_6O_{10}$ (CLBO) crystal and a $Li_2B_4O_7$ (LB4) crystal.

[0061]

It is a matter of course, that the wavelength conversion unit 163 shown in Fig. 4 is a mere example, and the arrangement of the wavelength conversion unit, the material of the nonlinear optical crystal, the output wavelength and the like in the present invention are not limited to it. For example, ultraviolet light having a wavelength of 157nm, which is the same as the F_2 laser, may be generated by performing a tenth-harmonic generation on the fundamental wave having a wavelength of 1.57μm emitted from the light amplifying portion 161 using the nonlinear optical crystal.

[0062]

Referring back to Fig. 2, the beam monitor mechanism 164 is made up of a Fabry-Perot etalon (hereinafter also referred to as "etalon element") and an energy monitor consisting of a photoconversion element such as a photodiode (neither is shown in Figs.). The beam incident on the etalon element structuring the beam monitor mechanism 164 passes through the etalon element with a transmittance that corresponds to the frequency difference of the resonance frequency of the etalon element and the frequency of the incident beam. And the output signals of the photodiode and the like, which have detected the intensity of the transmitted beam, are sent to the laser controller 16B. The laser controller 16B performs a predetermined signal processing on the output signals, and obtains information related to the optical properties of the incident beam on the beam monitor mechanism 164, to be precise, on the etalon element (to be concrete, information such as the center wavelength of the incident beam and the width of the wavelength (spectral half-width)). And the information related to the optical properties is sent to the main controller 50 realtime.

[0063]

In addition, the output of the energy monitor structuring the beam monitor mechanism 164 is sent to the main controller 50, and the main controller 50 detects

the energy power of the laser beam based on the output of the energy monitor and controls the light amount of the laser beam oscillated from the DFB semiconductor laser 160A via the laser controller 16B or turns off the DFB semiconductor laser 160A when necessary.

[0064]

The absorption cell 165 is an absolute wavelength source for absolute wavelength calibration of the oscillation wavelength of the DFB semiconductor laser 160A, in other words, is the absolute wavelength source for absolute wavelength calibration of the beam monitor mechanism 164. In the embodiment, since the DFB semiconductor laser 160A having the oscillation wavelength of 1.544μm is used as the light source, an isotope of acetylene having dense absorption lines in the wavelength band around the wavelength of the DFB semiconductor laser 160A is used as the absorption cell 165.

[0065]

In the case of selecting intermediate waves of the wavelength conversion unit 163 (such as the second-harmonic wave, the third harmonic wave, and the fourth harmonic wave) or light which wavelength has been converted with, or in alternate of the fundamental wave as the light for monitoring the wavelength of the laser beam, the absorption cell that has dense absorption lines around the wavelength of the intermediate wave can be

used. For example, in the case of selecting the third-harmonic wave as the light for monitoring the wavelength of the laser beam, iodine molecules that have dense absorption lines around the wavelength of 503nm to 530nm can be used as the absorption cell. The appropriate absorption line of the iodine molecules can be chosen, and the wavelength of the absorption line can be determined as the absolute wavelength.

[0066]

In addition, the absolute wavelength source is not limited to the absorption cell, and the absolute wavelength light source may also be used.

[0067]

The laser controller 16B detects the center wavelength and the wavelength width (spectral half-width) of the laser beam based on the output of the beam monitor mechanism 164, and feedback controls the temperature control (and current control) of the DFB semiconductor laser 160A so that the center wavelength becomes a desired value (set wavelength). In the embodiment, it is possible to control the temperature of the DFB semiconductor laser 160A in the unit of 0.001°C.

[0068]

In addition, the laser controller 16B switches the output of the DFB semiconductor 160A between the pulse output and the continuous output and controls the output interval and pulse width during pulse output, as well as

control the oscillation of the DFB semiconductor laser 160A so as to compensate the output variation of the pulse light, in accordance with instructions from the main controller 50.

[0069]

In this manner, the laser controller 16B stabilizes the oscillation wavelength to a constant wavelength, as well as finely adjusts the output wavelength. On the contrary, the laser controller 16B may also adjust the output wavelength of the DFB semiconductor laser 160A by positively changing the oscillation wavelength in accordance with instructions from the main controller 50.

[0070]

Referring back to Fig. 1, the illumination optical system 12 has a structure including: an illuminance uniformizing optical system made up of a fly-eye lens and the like; a relay lens; a variable ND filter; a reticle blind; and a dichroic mirror and the like (neither is shown in Figs.). Details of such arrangement of the illumination optical system are disclosed in, for example, Japanese Patent Laid Open No. 10-112433. The exposure light IL emitted from the illumination optical system 12 passes through a condenser lens 32 and illuminates a rectangular illumination area 42R on the reticle R held on the reticle stages RST with a uniform illuminance distribution, after its optical path is bent vertically downwards by a mirror M.

[0071]

The reticle R is mounted on the reticle stage RST, and is held on the stage by vacuum chucking (not shown in Figs.). The reticle stage RST is finely drivable within a horizontal surface (XY plane), as well as scanned in the scanning direction (in this case, the Y direction, being the landscape direction in Fig. 1) within a predetermined stroke range by the reticle stage driving portion 49. The position and rotational amount of the reticle stage RST during scanning, is measured via the movable mirror 52R fixed to the reticle stage RST by the laser interferometer 54R arranged externally, and the measurement values of the laser interferometer 54R is supplied to the main controller 50.

[0072]

The material used for the reticle R depends on the wavelength of the exposure light IL. That is, in the case of using exposure light with the wavelength of 193nm, synthetic quartz can be used. In the case of using exposure light with the wavelength of 157nm, however, the reticle R needs to be made of fluorite, fluorine-doped synthetic quartz, or crystal.

[0073]

The projection optical system PL is, for example, a double telecentric reduction system, and is made up of a plurality of lens elements which have a common optical axis AX in the Z-axis direction. In addition, as the

projection optical system PL, a projection optical system having a projection magnification β of, for example, 1/4, 1/5, or 1/6, is used. Therefore, when the illumination area 42R on the reticle R is illuminated with the exposure light IL as is described earlier, the pattern formed on the reticle R is projected and transferred as a reduced image by the projection magnification β with the projection optical system PL on the slit-shaped exposure area 42W on the wafer W, which surface is coated with the resist (photosensitive agent).

[0074]

The XY stage 14 is driven two-dimensionally, in the Y direction, which is the scanning direction, and in the X direction, which is perpendicular to the Y direction (the direction perpendicular to the page surface of Fig. 1), by the wafer stage driving portion 56. The Z tilt stage 58 is mounted on the XY stage 14, and on the Z tilt stage 58, the wafer W is held via a wafer holder (not shown in Figs.) by vacuum chucking and the like. The Z tilt stage 58 has the function of adjusting the position of the wafer W in the Z direction by for example, three actuators (piezo elements or voice coil motors), and also the function of adjusting the tilting angle of the wafer W in respect to the XY plane (image plane of the projection optical system PL). In addition, the position of the XY stage 14 is measured via the movable mirror 52W fixed on the Z tilt stage 58 by the laser interferometer

54W, which is externally arranged, and the measurement values of the laser interferometer 54W is sent to the main controller 50.

[0075]

As the movable mirror, in actual, an X movable mirror that has a reflection plane perpendicular to the X-axis and a Y movable mirror that has a reflection plane perpendicular to the Y-axis are arranged, and in correspondence with these mirrors, interferometers for an X-axis position measurement, Y-axis position measurement, and rotation (including yawing amount, pitching amount, and rolling amount) measurement are respectively arranged. In Fig. 1, however, these are representatively shown as the movable mirror 52W and the laser interferometer 54W.

[0076]

On the Z tilt stage 58, the fiducial mark plate FM used when performing operations such as reticle alignment, which will be described later, is arranged. The fiducial mark plate FM is arranged so that the height of the surface is almost the same as that of the surface of the wafer W. On the surface of the fiducial mark plate FM, fiducial marks for reticle alignment, baseline measurement, and the like, are formed.

[0077]

Also, it is omitted in Fig. 1 to avoid complication in the drawing, in actual, the exposure apparatus 10 comprises a reticle alignment system to perform reticle

alignment.

[0078]

When alignment is performed on the reticle R, first of all, the main controller 50 drives the reticle stage RST and the XY stage 14 via the reticle stage driving portion 49 and the wafer stage driving portion 56 so that the fiducial mark for reticle alignment on the fiducial mark plate FM is set within the exposure area 42W having a rectangular shape and the positional relationship between the reticle R and the Z tilt stage 58 is set so that the reticle mark image on the reticle R almost overlaps the fiducial mark. In this state, the main controller 50 picks up the image of both marks using the reticle alignment system, processes the pick-up signals, and calculates the positional shift amount of the projected image of the reticle mark in respect to the corresponding fiducial mark in the X direction and the Y direction. When picking up such an image of the mark, since the image is picked up via the projection optical system PL, a light having the almost same wavelength as the wavelength of the exposure light is used.

[0079]

In addition, it is also possible to obtain the focus offset and leveling offset (the focal position of the projection optical system PL, image plane tilt, and the like) based on information on contrast, which is included in the detection signals (picture signals) of the

projected image of the fiducial marks obtained as a consequence of the reticle alignment described above.

[0080]

Also, in the embodiment, when the reticle alignment is performed, the main controller 50 also performs measurement using a predetermined mark on a reference mark plate with respect to a baseline amount of the off-axis alignment sensor on the wafer side (not shown in Figs.) arranged on the side surface of the projection optical system PL (the positional relationship between a reticle projection position and the alignment sensor).

[0081]

Furthermore, as is shown in Fig. 1, with the exposure apparatus 10 in the embodiment, it has a light source which on/off is controlled by the main controller 50, and a multiple focal position detection system (a focus sensor) based on the oblique incident method is arranged, consisting of an irradiation optical system 60a which irradiates light from an incident direction in respect to the optical axis AX to form multiple pinhole or slit images toward the image forming plane of the projection optical system PL, and of an photodetection optical system 60b which photo-detects the light reflected off the surface of the wafer W. Details on the structure of the multiple focal position detection system (a focus sensor) similar to the one used in the embodiment, are disclosed in, for example, Japanese Patent Laid Open No.

06-283403.

[0082]

When performing scanning exposure, the main controller 50 performs automatic focusing and automatic leveling, by sequentially calculating a Z position and a tilt amount of a surface of a part of a shot area within the exposure area based on a Z position detected at each measurement position from the photodetection optical system 60b, and controlling the Z position of the Z tilt stage 58 via the driving system (not shown in Figs.) based on the calculation results.

[0083]

The main controller 50 is structured including a so-called microcomputer (or workstation) made up of components such as a CPU (central processing unit), a ROM (Read Only Memory), a RAM (Random Access Memory), and the like. Other than performing various controls described so far, the main controller 50 controls, for example, the synchronous scanning of the reticle R and the wafer W, the stepping operation of the wafer W, the exposure timing, and the like so that the exposure operation is performed accurately. In addition, in the embodiment, the main controller 50 has control over the whole apparatus, besides controls such as controlling the exposure amount on scanning exposure as will be described later.

[0084]

To be more precise, for example, on scanning exposure,

the main controller 50 respectively controls the position and velocity of the reticle stage RST and the XY stage 14 via the reticle stage driving portion 49 and the wafer stage driving portion 56 so that the wafer W is scanned via the XY stage 14 at the velocity $V_W=\beta\cdot V$ (β is the projection magnification from the reticle R to the wafer W) in the -Y direction (or +Y direction) in respect to the exposure area 42W, in synchronous with the reticle R scanned via the reticle stage RST at the velocity $V_R=V$ in the +Y direction (or -Y direction), based on the measurement values of the laser interferometers 54R and 54W. Also, when performing stepping operations, the main controller 50 controls the position of the XY stage 14 via the wafer stage driving portion 56, based on the measurement values of the laser interferometer 54W.

[0085]

The exposure sequence of the exposure apparatus 10 in the embodiment will be described next, when exposure on predetermined slices (N slices) of wafers W is performed to transfer the reticle pattern onto the wafer W, while mainly referring to the controls performed by the main controller 50.

[0086]

First, the main controller 50 loads the reticle R subject to exposure on the reticle stage RST, using the reticle loader (not shown in Figs.).

[0087]

Next, the reticle alignment is performed, using the reticle alignment system, as well as the baseline measurement.

[0088]

Then, the main controller 50 instructs the wafer carriage system (not shown in Figs.) to exchange the wafer W. By the instructions, the wafer is exchanged (or simply loaded when there are no wafers on the stage) by the wafer carriage system and the wafer delivery mechanism (not shown in Figs.) on the XY stage 14. When this is completed, a series of operations in the alignment process are performed, such as the so-called search alignment and fine alignment (EGA and the like). Since the wafer exchange and the wafer alignment are performed likewise, as is performed with the well-acknowledged exposure apparatus, the more detailed description is omitted here.

[0089]

Next, the reticle pattern is transferred onto a plurality of shot areas on the wafer W based on the step-and-scan method by repeatedly performing the operation of moving the wafer W to the starting position for scanning to expose each shot area on the wafer W and the scanning exposure operation. During this scanning exposure, in order to provide the target exposure amount to the wafer W, which is decided in accordance with exposure conditions and the resist sensitivity, the main

controller 50 gives instructions to the light amount controller 16C, and controls the exposure light amount.

[0090]

When exposure on the first wafer W is completed, the main controller 50 instructs the wafer carriage system (not shown in Figs.) to exchange the wafer W. Wafer exchange is thus performed, by the wafer carriage system and the wafer delivery mechanism (not shown in Figs.) on the XY stage 14, and after the wafer exchange is completed, search alignment and fine alignment is performed likewise as is described above to the wafer that has been exchanged.

[0091]

And, in the manner described earlier, the reticle pattern is transferred onto the plurality of shot areas on the wafer W based on the step-and-scan method.

[0092]

When the illuminance changes due to the change of the exposure conditions and/or the reticle pattern, it is preferable to control at least either the frequency or the peak power referred to above so as to provide the suitable exposure amount to the wafer (resist). On this control, in addition to adjusting at least either the frequency or the peak power, the scanning velocity of the reticle and the wafer may also be adjusted.

[0093]

As have been described above, with the light source

unit 16 related to the embodiment, since the amplifying fiber 175 mainly made of phosphate glass densely doped with a rare-earth element is used, the amplifying fiber 175 being short in length can amplify the incident light with high amplification. Therefore, light with high luminance can be supplied to the wavelength conversion unit 163, while reducing change in the polarized state that is generated when the light passes through the amplifying fiber 175. In addition, upon amplification, the length of the path where the light passes through is shorter, therefore, broadening in spectral width due to guided Raman scattering or self-phase modulation can be suppressed. Accordingly, a narrow-banded wavelength converted light can be efficiently generated with a simple arrangement.

[0094]

In addition, since the amplifying fiber 175 is arranged in a linear state, asymmetric stress being generated in the diameter direction, which causes change in the polarized state, can be prevented, therefore, the output light almost maintaining the polarized state at the incident stage can be obtained.

[0095]

Also, since the amplifying fiber 175 is housed in the container 176 having a nearly sealed structure, change in the surrounding environment of the amplifying fiber 175, which is the cause of change in the polarized state, can

be prevented, thus a stable wavelength conversion can be performed.

[0096]

In addition, since the wavelength conversion unit 163 has a structure including the nonlinear optical crystal (183, 186, 187, 195, 198) which performs wavelength conversion of the incident light, a wavelength converted light having high intensity can be obtained.

[0097]

In addition, the exposure apparatus 10 related to the embodiment uses the light source unit 16 as described above that generates an ultraviolet light suitable for transferring fine patterns, and accordingly the pattern can be efficiently transferred onto the wafer W.

[0098]

The exposure apparatus 10 in the embodiment above is made by assembling various subsystems so as to keep a predetermined mechanical precision, electrical precision, and optical precision. In order to ensure these areas of precision, prior to and after the assembly, adjustment (for example, optical axis adjustment) is performed on various optical systems such as the illumination optical system 12 and the projection optical system PL to attain a predetermined optical precision, adjustment is performed on various mechanical systems to attain a predetermined mechanical precision, and adjustment is performed on various electrical systems to attain a

predetermined electrical precision, respectively. Of these adjustments, since the light source for adjustment (testing) does not require high power when the properties of various optical systems are adjusted, with the light source 16 previously described, the arrangement can be simplified so as to use one or several fiber amplifiers 167 as the light source. In such a case, light having almost the same wavelength as the wavelength of the exposure light can be easily generated, and can be used for adjustment. Therefore, an accurate adjustment can be made with a cost effective light source having a simple arrangement. In the case of simplifying the arrangement so that only one fiber amplifier 167 is used, then the branching device 166 will not be required.

[0099]

The exposure apparatus 10 is assembled by mechanically connecting various subsystems assembled as described above, wiring electrical circuits, and piping pressure circuits. After the process of assembling various subsystems into the exposure apparatus is completed, total adjustment is performed to ensure preciseness in the overall exposure apparatus. In such overall adjustment as well, the simplified light source can be used when necessary. The exposure apparatus is preferably made in a clean room in which temperature, degree of cleanliness, and the like are controlled.

[0100]

Next, a device manufacturing method using the exposure apparatus and method according to the embodiment will be described.

[0101]

Fig. 5 is a flow chart showing an example of producing a device in the embodiment (a semiconductor chip such as an IC or LSI, a liquid crystal panel, a CCD, a thin magnetic head, a micromachine, or the like). As shown in Fig. 5, in step 201 (design step), function is designed for a device (e.g., circuit design for a semiconductor device) and a pattern to implement the function is designed. In step 202 (mask manufacturing step), a mask on which the designed circuit pattern is formed is manufactured. In step 203 (wafer manufacturing step), a wafer is manufactured by using a silicon material or the like.

[0102]

Next, in step 204 (wafer processing step), an actual circuit and the like is formed on the wafer by lithography using the mask and wafer prepared in steps 201 to 203, as will be described later. In step 205 (device assembly step), a wafer processed in the step 204 is assembled into a chip. Step 205 includes processes such as assembling (dicing, and bonding), and packaging (chip encapsulation) depending on the requirements.

[0103]

Finally, in step 206 (inspection step), a test on the

operation of the device, durability test, and the like are performed. After these steps, the device is completed and shipped out.

[0104]

Fig. 6 is a flow chart showing a detailed example of step 204 described above in manufacturing the semiconductor device. Referring to Fig. 6, in step 211 (oxidation step), the surface of the wafer is oxidized. In step 212 (CVD step), an insulating film is formed on the wafer surface. In step 213 (electrode formation step), an electrode is formed on the wafer by vapor deposition. In step 214 (ion implantation step), ions are implanted into the wafer. Steps 211 to 214 described above constitute a pre-process for the respective steps in the wafer process and are selectively executed in accordance with the processing required in the respective steps.

[0105]

When the pre-process is completed in the respective steps in the wafer process, a post-process is executed as follows. In this post-process, first, in step 215 (resist formation step), the wafer is coated with a photosensitive agent, and next in step 216 (exposure step), the circuit pattern on the mask is exposed and printed onto the wafer by the above exposure apparatus 10. Then, in step 217 (developing step), the exposed wafer is developed. In step 218 (etching step), an exposed member on a portion other than a portion where the resist is

left is removed by etching. Finally, in step 219 (resist removing step), the unnecessary resist after the etching is removed.

[0106]

By repeatedly performing these pre-process and post-process steps, multiple circuit patterns are formed on the wafer.

[0107]

In the manner described above, devices on which fine patterns are formed with good precision are manufactured with high mass productivity.

[0108]

In the above embodiment, as the amplifying fiber 175, the optical fiber mainly made of phosphate glass is used, however, it is possible to use an optical fiber mainly made of bismuth oxide glass ($Bi_2O_3B_2O_3$). With the bismuth oxide glass, the amount of erbium doped can be 100 times and over, compared with the conventional silica glass, and can obtain similar effect as in the case of phosphate glass.

[0109]

In the embodiment, the laser light source 160A is not limited to semiconductor lasers such as the DFB semiconductor laser. For example, the ytteribium (Yb) doped fiber laser which has an oscillation wavelength of around 990nm can be used.

[0110]

In addition, with the above embodiment, as the amplifying fiber, the Er-doped fiber is employed, however, it is possible to employ the Yb-doped fiber and other rare-earth element doped fibers.

[0111]

Also, with the above embodiment, the optical fiber type member is used as the amplifying optical waveguide member, however, it is also possible to use other options, such as the planar type waveguide member.

[0112]

Also, the number of fiber amplifiers arranged in parallel in the light amplifying portion may be any number, and the number can be determined depending on the product in which the light source unit related to the present invention is applied, such as, the specification (illuminance on the wafer) and optical properties required in the exposure apparatus, that is, the transmittance of the illumination optical system and the projection optical system, the conversion efficiency of the wavelength conversion unit, and the output of each optical path. Even in such a case, the frequency control of the pulse light emitted from the optical modulating unit referred to earlier, and light amount, exposure amount control by peak power control can be suitably applied.

[0113]

Furthermore, the wavelength of the ultraviolet light

is set almost the same as that of the ArF excimer laser in the embodiment above, however, the set wavelength may be of any wavelength, and the oscillation wavelength of the laser light source 160A, the structure of the wavelength conversion unit 163, and the magnification of the harmonic wave may be decided according to the set wavelength. As an example, the set wavelength may be set in accordance with the design rule (such as the line width and pitch) of the pattern to be transferred onto the wafer, moreover, on deciding the set wavelength, the exposure conditions and the type of reticle (whether the reticle is the phase shift type or not) previously referred to may be considered.

[0114]

In addition, although it is not specifically referred to in the description above, with the exposure apparatus which performs exposure using the wavelength of 193nm and under as in the embodiment, measures such as filling or creating a flow of clean air that has passed through a chemical filter, dry air, N_2 gas, or inert gas such as helium, argon, or krypton in the passage of the exposure beam, or vacuuming the passage of the exposure beam, need to be taken.

[0115]

Also, in the embodiment above, the case has been described when the light source unit is used in a scanning exposure apparatus based on the step-and-scan

method, however, the light source unit related to the present invention can be applied in units used in the device manufacturing process and the like besides the exposure apparatus, for example, in a laser repair unit used to cut off a part of a circuit pattern (such as a fuse) formed on a wafer. In addition, the present invention is not limited to the scanning exposure apparatus based on the step-and-scan method, and can be suitably applied to the static exposure type, for example, to the exposure apparatus based on the step-and-repeat method (such as the stepper). Furthermore, the present invention can also be applied to the exposure apparatus based on the step-and-stitch method, to the mirror projection aligner, and the like.

[0116]

In addition, with the embodiment above, the example has been described when the light source unit related to the present invention is used for the light source to generate the illumination light for exposure, however, it is also possible to use the light source for reticle alignment described above, which requires almost the same wavelength as that of the illumination light for exposure. In this case, it is a matter of course that the light source unit of the simplified arrangement described above is used.

[0117]

Of course, the present invention can be suitably

applied to not only the exposure apparatus used to manufacture a semiconductor device, but also to the exposure apparatus used to manufacture a display including the liquid crystal display device that transfers the device pattern onto a glass plate, to the exposure apparatus used to manufacture a thin-film magnetic head that transfers the device pattern onto a ceramic wafer, to the exposure apparatus used to manufacture a pick-up device (such as a CCD), a micromachine, a DNA chip, and furthermore, to the exposure apparatus used to manufacture a mask or a reticle.

[0118]

Furthermore, the light source of the present invention can be utilized in units other than the exposure apparatus, for example, as the light source unit in the optical testing unit and the like. Also, the light source of the present invention can be used as the light source in the unit to perform eyesight correction by irradiating ultraviolet light on the eyeground. Moreover, the light source of the present invention can be used in various exposure apparatus using the excimer laser beam.

[0119]

[EFFECT OF THE INVENTION]

As have been described above, with the light source unit according to the present invention, since the optical waveguiding member mainly made of either

phosphate glass or bismuth oxide glass densely doped with a rare-earth element is used, a light having a predetermined wavelength can be efficiently generated with a simple arrangement.

[0120]

In addition, with the exposure apparatus according to the present invention, since the exposure apparatus comprises the light source unit according to the present invention serving as a light source unit which generates light which wavelength belongs to a predetermined bandwidth including a wavelength of the exposure light, the narrow-banded light can be efficiently supplied in the case the generation of the exposure light or a light having the almost same wavelength as the exposure light is needed.

[0121]

In addition, with the method of making an exposure apparatus according to the present invention, upon adjustment of properties in the optical system which the exposure light passes through, light which is generated by the light source unit according to the present invention and of which wavelength belongs to a predetermined bandwidth including a wavelength of the exposure light is used, and therefore, the adjustment of the properties of the optical system can be performed easily, with high precision.

[0122]

In addition, with the device manufacturing method according to the present invention, since exposure is performed using the exposure apparatus according to the present invention, a device with high integration and high performances can be efficiently manufactured.

[BRIEF DESCRIPTION OF THE DRAWING]

[FIG. 1]

Fig. 1 is a schematic view showing the configuration of the exposure apparatus of the embodiment in the present invention.

[FIG. 2]

Fig. 2 is a block diagram showing the internal structure of the light source unit in Fig. 1 with the main control unit.

[FIG. 3]

Fig. 3 is a schematic view showing the fiber amplifiers structuring the light amplifying portion in Fig. 2 and its neighboring portion, with a part of the wavelength conversion unit.

[FIG. 4]

Fig. 4 is a view showing an arrangement of a wavelength conversion unit.

[FIG. 5]

Fig. 5 is a flow chart explaining a device manufacturing method using the exposure apparatus shown in Fig. 1.

[FIG. 6]

Fig. 6 is a flow chart showing the processing in a wafer processing step in Fig. 5.

[DESCRIPTION OF REFERENCED LETTERS/NUMERALS]

10	Exposure apparatus
16	Light source unit
167	Fiber amplifier (Light amplifying unit)
163	Wavelength conversion unit
175	Amplifying fiber (Optical waveguiding member)
W	Wafer (Substrate)

[DOCUMENT NAME] ABSTRACT

[ABSTRACT]

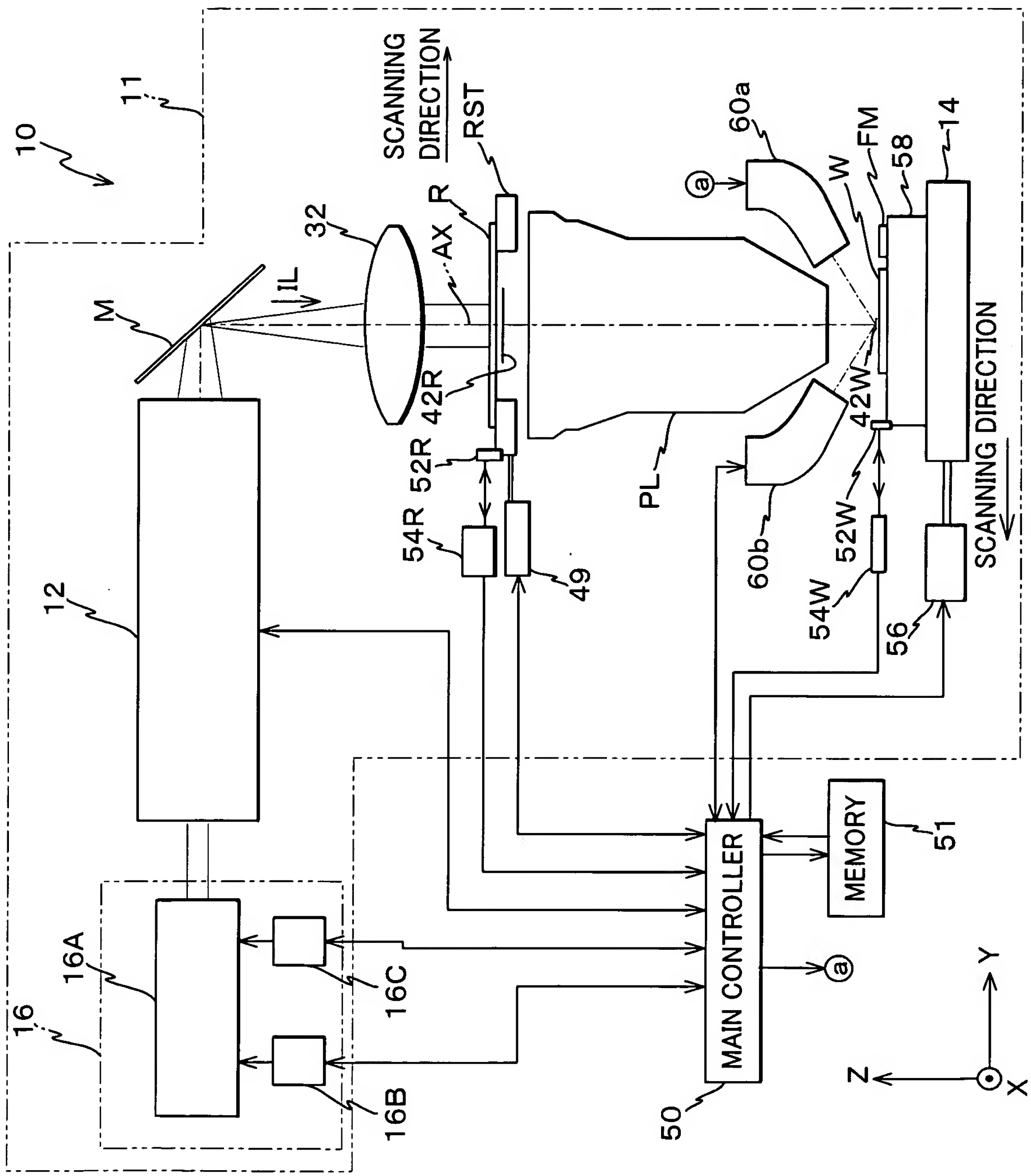
[PROBLEMS TO BE SOLVED]

To efficiently generate light having a predetermined wavelength with a simple arrangement.

[SOLUTION]

A light amplifying unit 167 is structured using an optical waveguiding member 175 mainly made of either phosphate glass or bismuth oxide glass and densely doped with a rare-earth element. Consequently, the optical waveguiding member 175 being short in length can amplify the incident light with high amplification. Therefore, light having a high intensity can be supplied to a wavelength conversion unit 163, while reducing change in a polarized state which is generated when the light passes through the optical waveguiding member. In addition, since the length of the path where the light passes through upon amplification is shorter, the broadening in spectral width due to guided Raman scattering or self-phase modulation can be suppressed. Accordingly, a narrow-banded wavelength converted light can be efficiently generated with a simple arrangement.

[DRAWING] FIG. 3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MAIN CONTROLLER
MEMORY
SCANNING DIRECTION
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12
14
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16B
16C
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42W
49
50
51
52R
52W
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FM
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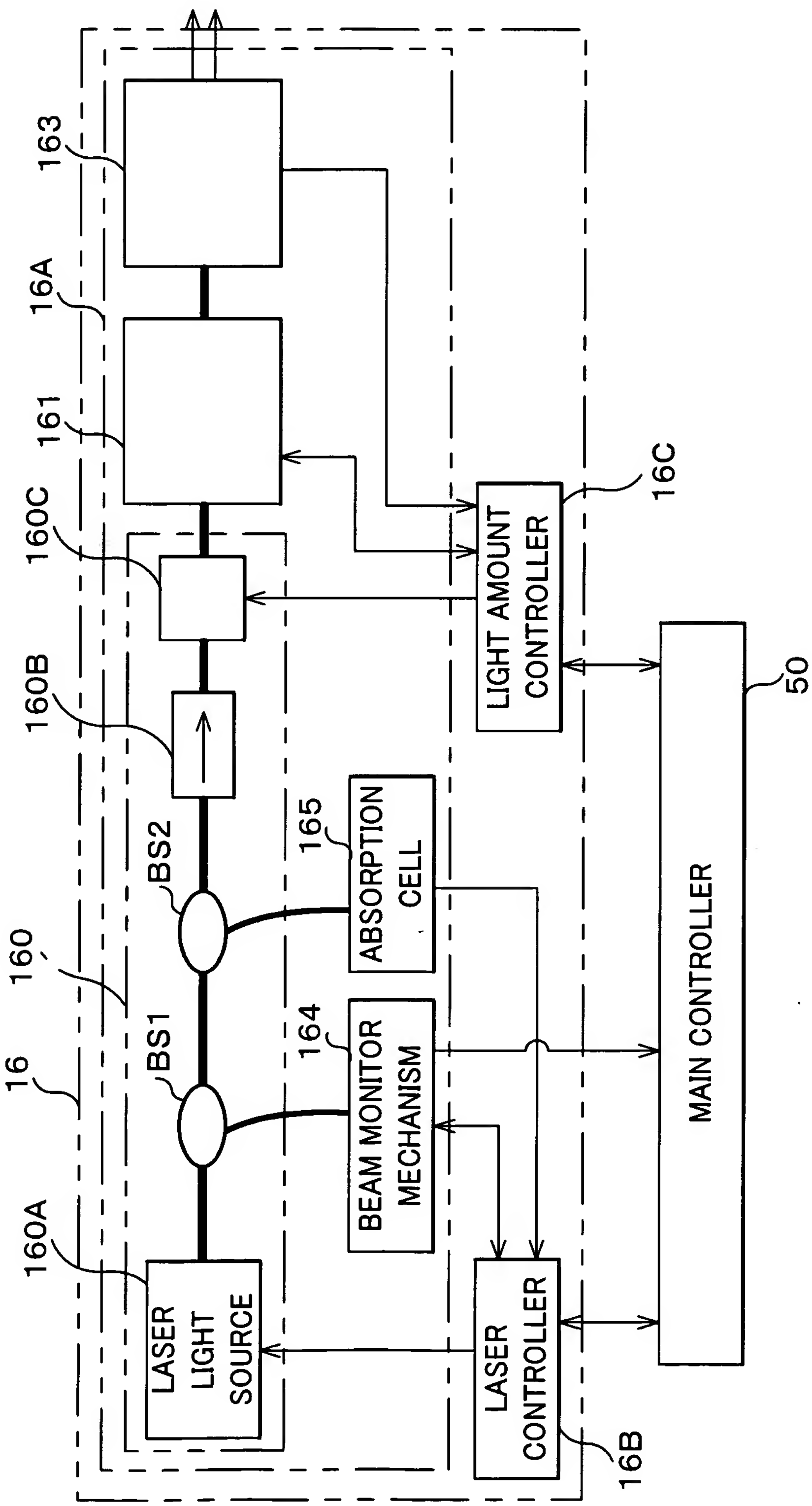
Y
X

Fig. 2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160
160A
160B
160C
161
163
BS1
BS2
LASER LIGHT SOURCE
BEAM MONITOR MECHANISM
164
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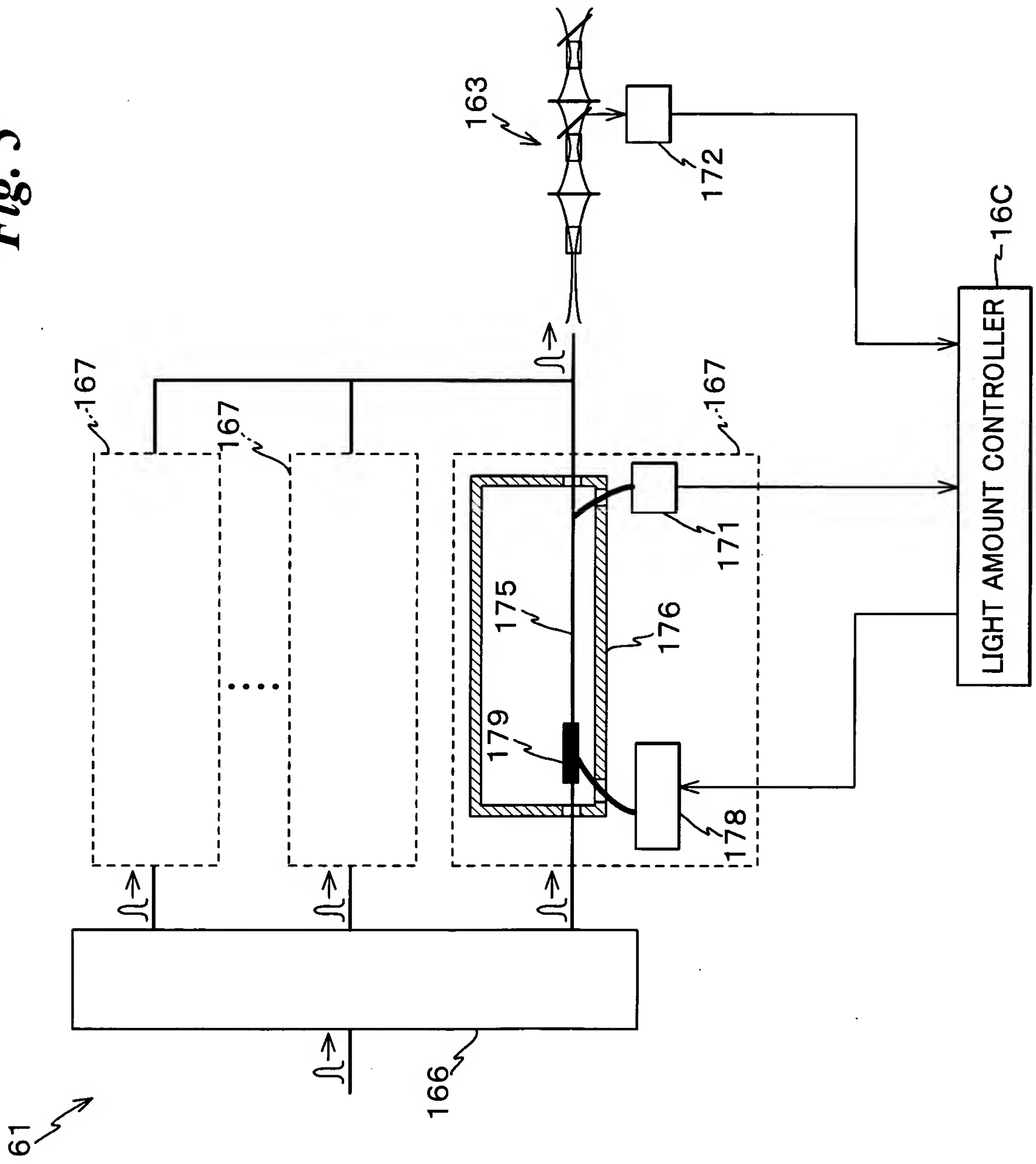
LASER CONTROLLER
16B
LIGHT AMOUNT CONTROLLER
16C
MAIN CONTROLLER
50

Fig. 3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167
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163
16C
LIGHT AMOUNT CONTROLLER

Fig. 4

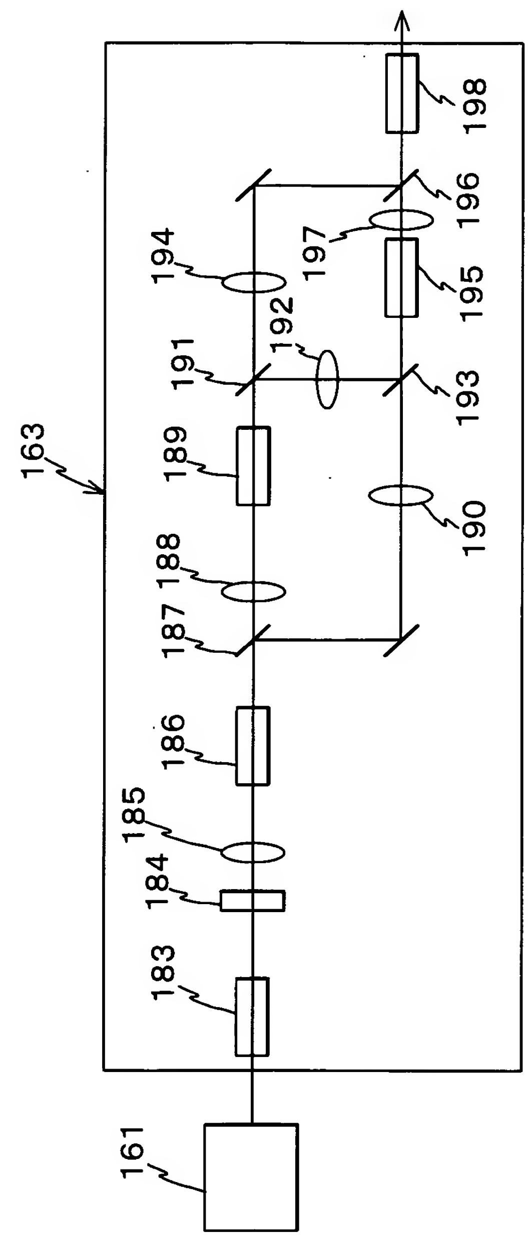
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Fig. 5

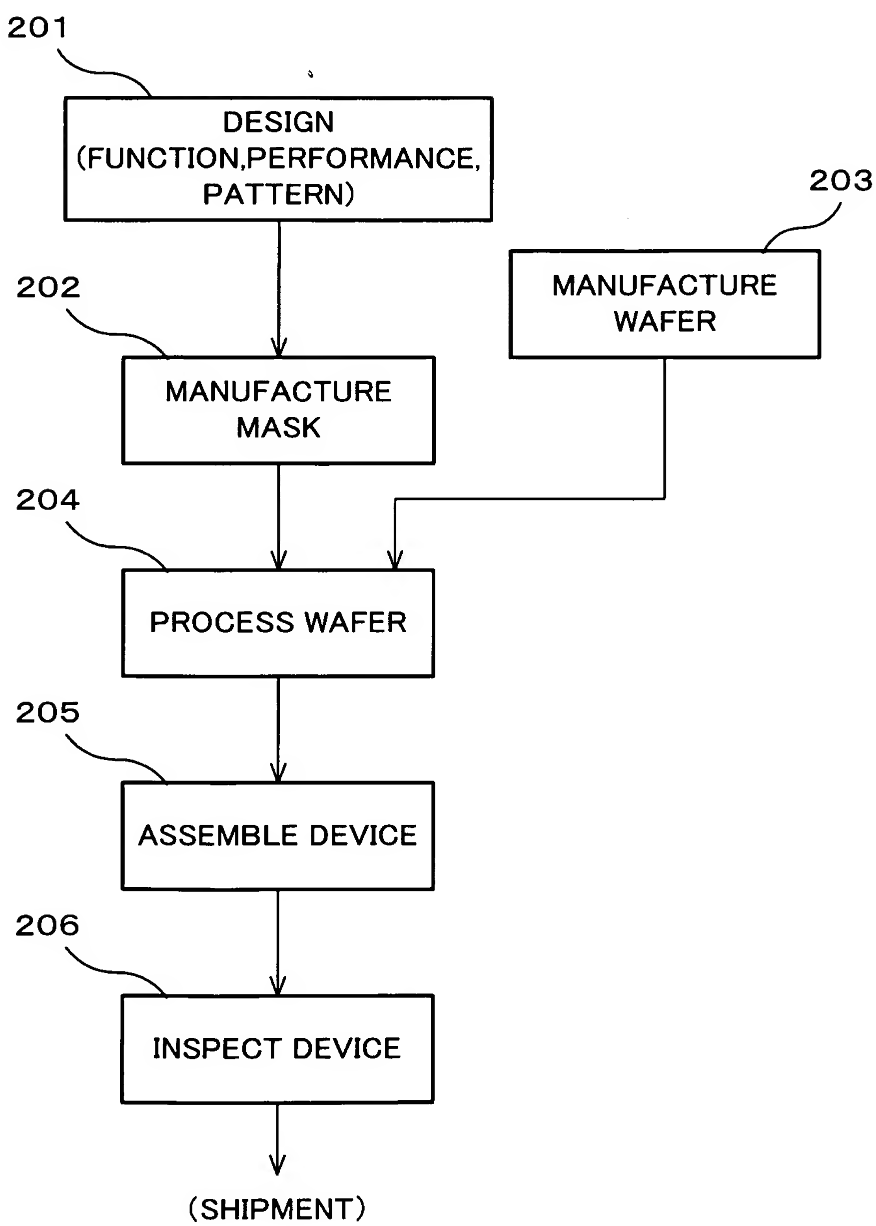
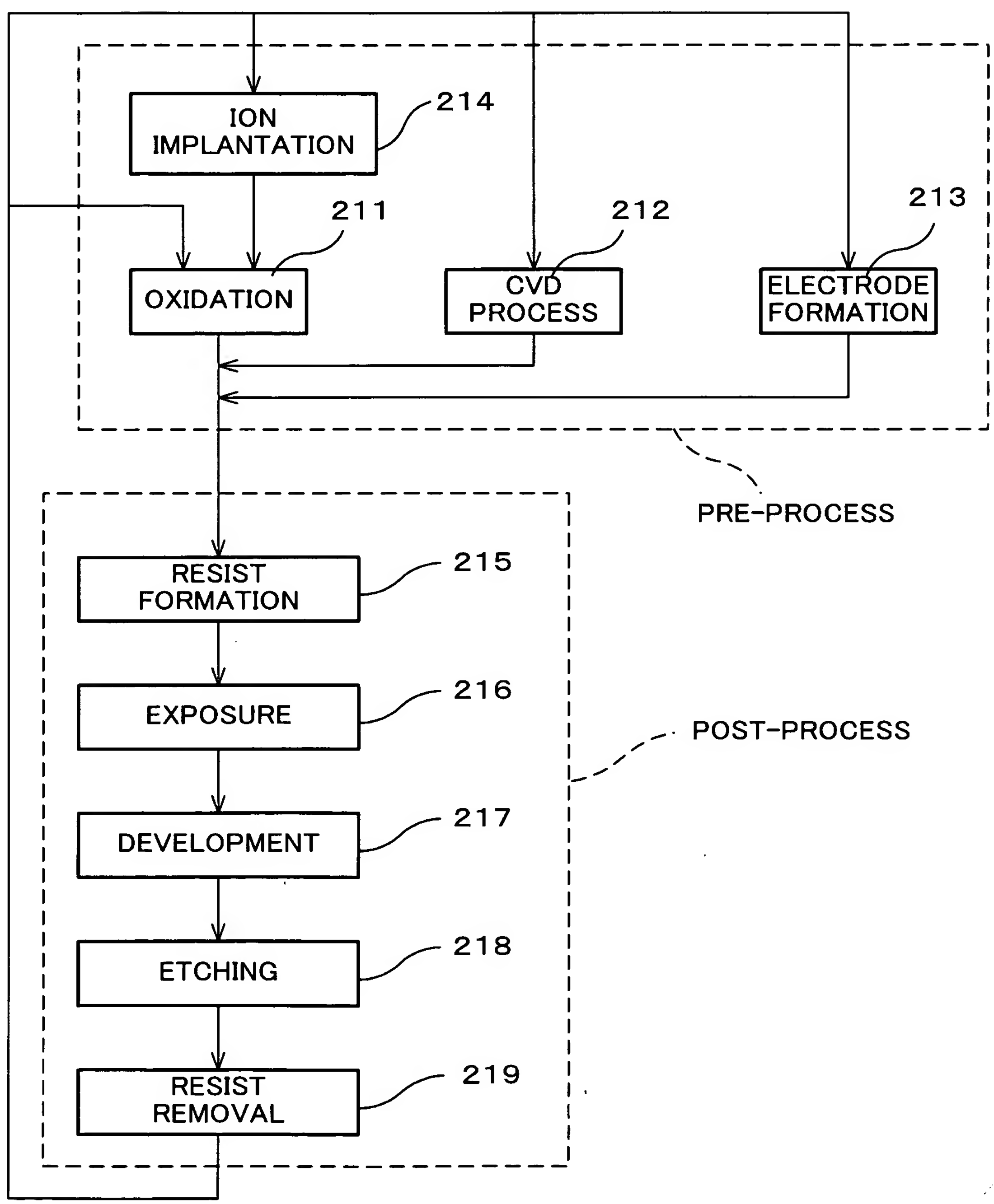

201
DESIGN
(FUNCTION,PERFORMANCE,
PATTERN)
203
MANUFACTURE
WAFER
202
MANUFACTURE
MASK
204
PROCESS WAFER
205
ASSEMBLE DEVICE
206
INSPECT DEVICE
(SHIPMENT)

Fig. 6


ION IMPLANTATION
214
211
212
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OXIDATION
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PRE-PROCESS
RESIST FORMATION
215
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216
POST-PROCESS
DEVELOPMENT
217
ETCHING
218
RESIST REMOVAL
219